

## **Making green technology greener**

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# **Making green technology greener: achieving a balance between carbon and resource savings through ecodesign in hydropower systems**

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## **Abstract**

Renewable energy systems reduce the greenhouse gas (GHG) emissions associated with energy generation. However, we live in a world with depleting reserves of natural resources, and significant quantities of raw materials are often embodied within renewable energy infrastructure. This paper examines the potential for ecodesign measures to improve the GHG and resource balance of five small-scale hydropower case studies (50-650 kW). A life cycle assessment (LCA) approach compares two specific environmental impact categories: global warming potential (GWP) and abiotic resource depletion potential (ARDP). A number of ecodesign measures were examined for each installation: powerhouse structure, concrete selection, roofing materials, excavation work and transportation. Ecodesign led to cumulative savings of between 2.1% and 10.4% for GWP, and ARDP savings of between 0.1% and 2.6%, for the hydropower installations. Small savings were made with each ecodesign measure applied in all case studies. Furthermore, applying a 1% materiality threshold as outlined by LCA standards was shown to under-estimate the total project burdens, and to neglect opportunities for burden savings through ecodesign. Ecodesign can promote the use

of locally sourced materials and some measures can lead to time savings during the construction process. The findings demonstrate the potential for ecodesign to modestly improve the carbon and resource efficiency of hydropower projects.

**Keywords:** life cycle assessment; global warming potential; abiotic resource depletion; environmental burdens; ecodesign; cradle-to-operation.

## **1 Introduction**

Renewable energy systems contribute an increasing fraction of global electricity supply (REN21, 2014). The International Energy Agency (IEA) have recognized this growth, with generation almost trebling between 1973 and 2011 to 3,566 TWh, and to further double to 7,000 by 2035 (IEA, 2014). For this sector to continue to expand, significant quantities of raw materials and energy will be used to manufacture these technologies. In a recent review by Asdrubali et al. (2015), the reported environmental impacts of renewable energy systems varied significantly between technologies, with wind and hydro providing the best results, while geothermal and photovoltaics (PV) generated significantly higher impacts. The majority of the environmental burdens for renewable technologies are associated with the infrastructural phase of the project life cycle, as opposed to the high contributions of emissions during the operational phase for fossil-fuel systems (Turconi et al., 2013). Overall, the environmental burdens (e.g. greenhouse gas emissions) of electricity generation from renewables over their life cycle are significantly lower than fossil-fuel systems, except in a number of cases for the abiotic resource depletion impact category (Gallagher et al., 2015a).

In comparison to other renewable technologies, hydropower infrastructure has the longest lifespan, and therefore could represent a highly effective method of investing our depleting

natural resources (Asdrubali et al., 2015). Hydropower (HP) is currently the largest contributor of renewable energy to global electricity production, providing over 16% of global electricity demands, which helps mitigate substantial greenhouse gas (GHG) emissions from fossil fuel combustion (REN21, 2014). The IEA (2014) report states that there is significant potential for further HP developments, with the Intergovernmental Panel on Climate Change (IPCC) stating that hydropower offers significant potential for carbon emission reductions (Kumar et al., 2011).

A recent paper by Bódis et al. (2014) suggested that 28,000 unexploited HP sites remain in Europe. Following this, Gallagher et al. (2015a) estimated the total potential as 7.35 TWh of additional generation which could offset 2.96 Mt of CO<sub>2</sub> from fossil fuel savings (Gallagher et al., 2015a). Studies have shown that the embodied carbon in HP projects ranges from 0.2 to 152 g CO<sub>2</sub> eq./kWh (Raadal et al., 2011), which is lower than the current average carbon footprint of European grid electricity of 352 g CO<sub>2</sub> eq./kWh (Defra, 2014). Other publications have presented the carbon footprint of different sized HP projects: 15 g CO<sub>2</sub> eq./kWh for a small HP plant (Gagnon & van de Vate, 1997); 35-75 g CO<sub>2</sub> eq./kWh for a range of sizes of HP plants (Varun et al., 2008); 53 g CO<sub>2</sub> eq./kWh for a micro HP installation (Pascale et al., 2011); 195 g CO<sub>2</sub> eq./kWh for a large HP project (Zhang & Xu, 2015). More recent studies have presented ‘cradle-to-operation’ results for small- and micro-HP projects installed in water supply infrastructure and run-of-river settings as low as 5-10 g CO<sub>2</sub> eq./kWh (Gallagher et al., 2015a, c).

Life cycle assessment (LCA) is a method of quantifying the environmental burdens for a product or service, such as a HP installation, through its life cycle (BSI, 2011). It provides a simple platform for comparison of HP projects with other fossil fuel electricity generation

systems (Raadal et al., 2011). However, a detailed database of raw materials and energy processes are required to accurately report the environmental burdens for these projects (Chomkhamsri & Pelletier, 2011; Curran, 2013). Carbon footprinting is considered as a universal method of presenting the environmental impacts of a product or service (BSI, 2011), and has been used as the sole indicator by a number of LCA studies for the construction industry (Kenny et al., 2010; Basbagill et al., 2013). Furthermore, guidelines developed by the Waste and Resource Action Programme (WRAP, 2012) outline carbon as the sole indicator for environmental impacts in material selection for the construction sector. The focus on carbon footprinting risks under- or over-estimating overall life cycle burdens, and savings potentials, when evaluating ecodesign options for renewable energy systems.

Significant quantities of embodied energy are included from raw materials, component manufacturing and construction of HP projects (Rule et al., 2009). However, reporting on the environmental impacts of renewable energy projects has typically focused on carbon. Rule et al. (2009) noted that the use of natural resources and embodied energy, or ‘emergy’, has not widely been used as an indicator of sustainability. The depletion of abiotic resources has received more interest in recent years as current production and demands for raw materials continues to grow (Muilerman & Blonk, 2001; Yellishetty et al., 2011; Klinglmair et al., 2014). The concept of ‘dematerialisation’ has been considered to reduce consumption by increasing material efficiency, promoting material shifts and increasing the reuse and recycling of products (van der Voet et al., 2004).

For the majority of LCA studies of HP installations, the focus has been on GHG emissions and the associated carbon footprint of a project. For example, Zhang et al. (2015) compared the carbon footprint of two HP projects, an earth-core rockfill dam (ECRD) and a concrete

dam, and demonstrated the potential to reduce CO<sub>2</sub> emissions by almost 25% using the ECRD design. This provides a positive outlook upon alternative construction methods, yet it only presented one environmental burden. It is important to examine a range of categories and taking an ecodesign approach to a project, even for a renewable energy system like a HP installation, as there is a need to examine the quantity of natural resources used in addition to the carbon footprint of materials and manufacturing processes.

The EU Directive 2009/125/EC defines ecodesign as ‘the integration of environmental aspects into product design, with the aim of improving the environmental performance of the product throughout its whole life cycle’ (EC, 2009). In 2012, the Energy Efficiency Directive demonstrated the commitment of the EU to achieving more energy efficient products (EC, 2015). In product design, ecodesign is presented as one method of minimizing the environmental burdens over a product’s lifespan (Zbicinski et al., 2006). Despite being considered in other industries (Sala et al., 2012; Basbagill et al., 2013), ecodesign has only recently been suggested for a renewable energy system (Gallagher et al., 2015a). An ecodesign approach to a renewable energy system, which is made up of a combination of multiple products, can maximize material and energy savings. Assuming ecodesign was applied to all 28,000 technically feasible HP projects identified by Bódis et al. (2014) for Europe, Gallagher et al. (2015a) estimated potential savings of 800,000 tonnes of concrete, 10,000 of steel and 65 million vehicle miles. As the majority of the environmental burdens for a renewable energy system are embodied in the design and construction stages, ecodesign presents a significant opportunity for carbon and resource savings in HP projects (D’Souza et al., 2011; Suwanit & Gheewala, 2011; Guezuraga et al., 2012).

This paper applies LCA to capture the environmental burdens of five small-scale HP projects, representing water supply infrastructure and run-of-river installations. Several potential ecodesign measures are examined for these projects. The results focus on carbon- and resource-based environmental burdens represented by global warming potential (GWP) and abiotic resource depletion potential (ARDP) impact categories, respectively. Finally, the study examines the implications for ecodesign of using the 1% materiality threshold commonly quoted in LCA guidelines for inventory compilation.

## **2 Methods**

### ***2.1 Goal & scope definitions***

This paper presents five distinct HP projects in the UK and Ireland, three run-of-river and two water supply network infrastructure projects, each of which required a unique combination of material quantities, manufacturing processes and component transport (Gallagher et al., 2015c). The focus of this paper is to consider ecodesign in the construction of these HP installations; therefore a ‘cradle-to-operation’ scope was adopted to account for all environmental impacts up to the stage of generating electricity. This scope was considered suitable as the vast majority of burdens are linked to the main project components required in the construction stage (Raadal et al., 2011). In addition, the end-of-life stage for HP installations is difficult to quantify due to typically long, though uncertain, operational lifespans and unknown future materials recycling performance (Haynes, 2010).

Two relevant environmental impact categories were selected from the CML impact assessment method: global warming potential (GWP), expressed as kg CO<sub>2</sub> eq., and abiotic resource depletion (ARDP), expressed as kg Sb eq. (CML, 2010). These categories represent the primary environmental burdens (climate change and resource depletion) associated with

hydro projects and grid electricity generation. Thus, the results of eco-design modifications are presented as percentage changes in these environmental burdens for the cradle-to-operation phase of deployment, relative to the standard designs reported in Gallagher et al. (2015a).

## 2.2 Inventory for LCA case studies

To accurately assess the environmental burdens of all project components, materials and processes, a complete and detailed inventory database was generated from previous life cycle HP investigations (Gallagher et al., 2015a; b; c) and is included in Table SI.1 in the Supplementary Information. The database of environmental burdens relate to raw material extraction, product manufacturing and transport burdens, and was generated in MS Excel. The Ecoinvent v.3 database accessed via SimaPro 8.0 software was used to calculate the environmental burdens of the HP installations (Ecoinvent, 2014). This study followed ISO 14040 standards for LCA (ISO, 2006), but included all material contributions for which there were data, including many below the 1% materiality threshold proposed in LCA standards.

## 2.3 Case study descriptions

Summary details for the five case studies (three run-of-river and two water infrastructure hydropower projects) are provided in Table 1 and **Error! Reference source not found.**

*Table 1. Description of five HP case studies (Gallagher et al., 2015b).*

Parameter	Run-of-river			Water infrastructure	
	Private	Hafod y Porth	Hafod y Llan	Vartry	Strata Florida
<b>Location</b>	North England	North Wales	North Wales	East Ireland	Mid Wales
<b>Net head</b>	105 m	128 m	175 m	7-16 m	183-196 m
<b>Flow</b>	~90 l/s	~100 l/s	~450 l/s	~580-1200 l/s	~100 l/s
<b>Design capacity</b>	50 kW	100 kW	650 kW	90 kW	140 kW
<b>Turbine type</b>	Turgo	Turgo	Pelton	Kaplan	Pelton
<b>Annual output*</b>	0.2-0.3 GWh	0.4-0.5 GWh	1.8-2.1 GWh	0.6-0.7 GWh	0.9-1.0 GWh

\* Annual output based on design for each HP project.



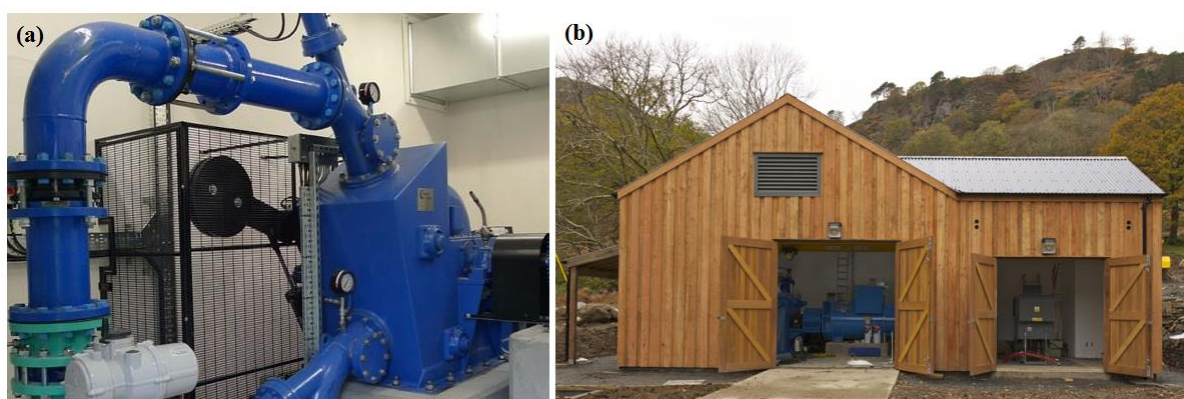


Figure 1. Photos of (a) 140 kW water infrastructure and (b) 650 kW run-of-river hydropower projects (Dŵr Cymru Welsh Water, 2013; National Trust Wales, 2014)

In addition, the assumptions for this LCA study are outlined in Table 2, based on comparable system boundaries across each project that account for all important contributory processes, including raw material extraction, manufacturing, transportation and construction.

Table 2. Assumptions made for life cycle assessment of HP projects (Gallagher et al., 2015b).

Assumptions	Details
Boundary conditions	Grid transmission infrastructure, operation/maintenance and decommissioning omitted.
Project lifespan	50-year lifespan for turbines, 100-year lifespan for pipework and housing (further details in Gallagher et al. (2015a; 2015c).
Raw materials, manufacturing, construction & transportation	Impact category data for raw materials (e.g. steel, concrete, etc.), manufacturing (e.g. steel product manufacturing) and transportation (e.g. freight transport) were sourced from Ecoinvent v.3 database via SimaPro8 (Ecoinvent, 2014). The environmental impacts of soil movement and construction processes were included; however, the impact of excess displaced soil/turf was omitted.
Products	Estimations for the mass of raw materials contained in turbine/generator units were based on consultation with project stakeholders.

## 2.4 Ecodesign measures

Ecodesign helps identify opportunities for economic and energy savings for a HP system (Lee et al., 2015). A recent driver has been the development of the EC Directive 2009/125/EC, which provides a framework for eco-design of energy-related products (EC, 2009; 2015). In the present study, no materiality threshold was applied for eco-design measures, to ensure all environmental burdens were captured in the LCA process. Therefore,

the baseline case for comparison of ecodesign measures accounted for all life cycle burdens associated with the development of the HP installations.

A number of ecodesign opportunities were identified based on exploring some of the opportunities considered for the construction industry (WRAP, 2012), and small measures taken in a previous HP case study (Gallagher et al., 2015c). Based on a study by van der Voet et al. (2004), ecodesign measures for HP projects include selection of more efficient materials, although there may be a trade-off if the project lifespan is reduced owing to reduced durability. However, the materials used in this study can effectively meet the 50-year project lifespan expected of the rest of the HP installation. The measures examined for HP installations in this study relate to: powerhouse structure, concrete selection, roofing materials, excavation work and transportation.

#### *Powerhouse structure*

In four of the five case studies from Gallagher et al. (2015b), the powerhouse construction presented a significant opportunity to apply ecodesign, accounting for 4.5 to 7.9% of total project burdens. The replacement of concrete block cavity walls with wooden frame superstructures can reduce the overall environmental impacts of materials used in the powerhouse, reducing the use of concrete blocks by 90%. To provide an adequate replacement of the block wall structure, the wood frame was treated, insulated with acoustic wool, covered in plasterboard and finished to a similar standard as the alternative building. The wood structure also presented a reduced loading of approximately 50% on the foundations (based on density of different materials). This allowed for a smaller foundation design and other knock-on resource savings.

### *Concrete selection*

The concrete used in the construction of the HP case studies contributed to between 12 and 29% of the total carbon-related burdens (Gallagher et al., 2015c). Three options are identified to reduce the environmental impacts of each project by (i) improving, (ii) replacing or (iii) reducing the use of concrete in the HP installations. Improvements in the use of concrete can be considered through more efficient designs and using pre-cast sections, which reduces waste material by an estimated 2.5% (both concrete and wood shuttering) during the construction of the HP installations (WRAP, 2012). Using 'green concrete' by replacing a fraction of the aggregate or cement with increased recycled content can also potentially reduce the environmental impacts of concrete used in the projects. The use of green concrete can therefore reduce the burden of the material used by approximately 2.5%. Lastly, if the structural loading of a powerhouse foundation is reduced by changing from a concrete block to wood frame super-structure, this allows for a redesign of the foundation and an estimated 5% reduction in the quantity of concrete required. This equated to a restrained cumulative 10% saving in the use of concrete for each HP project.

### *Roof material*

Promoting the use of local and traditional roofing materials such as slate tiles can replace corrugated iron sheeting for some powerhouses to reduce the environmental impacts associated with the sheet metal production. Despite a small increase in the load of slates as opposed to corrugated iron sheeting, it was assumed in this study that changing the roofing material would not change the structural design and frame of the building. This can also promote the use of local materials in renewable energy projects which helps the local economy; as well as bring aesthetic benefits.

### *Excavation work and transportation*

For run-of-river installations, long lengths of pipework, in excess of one kilometre, are required to flow into the turbine from the weir. This pipework typically winds through mountainous regions and pipe burial presents an energy-intensive activity for some of the case studies examined. To reduce the quantity of excavation and rock breaking, pipework can be laid on top of the ground and overlaid with stone to create a footpath or hidden behind a wall, as demonstrated in one case study (Gallagher et al., 2015c); with more recent work using net covers over the pipework on which moss is allowed to overgrow. For ecodesign, it was estimated that this measure would reduce rock breaking activities by 50%, reduce the quantity of excavation or fill material by 20% and overall energy transportation requirements by 10%.

Lastly, transportation of materials and personnel can contribute to the environmental impacts of a HP project. Thus, considering the use of local materials to reduce the distance that supplies are delivered to site, ensuring personal car-share to work, a reduction of materials required on site and on-site machinery using biofuels all present opportunities for primary fossil energy savings from transport related burdens.

### **2.5 *Materiality thresholds and ecodesign***

For quantifying the environmental impacts of a HP project, ISA (2014) noted that a complete dataset is required for the calculation of 100% of burdens. However, LCA guidelines include materiality thresholds which allows for minor contributions of less than 1% to be omitted from the study (ISO, 2006; BSI, 2011). A previous investigation by Gallagher et al. (2015b) outlined the issue of adopting this 1% materiality threshold, and adopted a 0.5% threshold to reduce the omission of components and underestimation of total environmental burdens

associated with HP projects. This study compares results when using a 1%, 0.5% or no materiality threshold in terms of identifying ecodesign opportunities.

### 3 Results and discussion

#### 3.1 Ecodesign measures

Not all ecodesign measures were applicable to each installation. The ecodesign measures applied included: four of the five projects adopting an alternative wood frame powerhouse super-structure; all projects using concrete savings strategies; some projects changed from current roof materials to local slate; excavation work was reduced; and a reduction strategy for material transport was considered. Based on these, the cumulative ecodesign savings for each HP project were calculated for the five environmental burdens and are presented in Table 3.

*Table 3. Environmental burden savings through ecodesign measures and activities for run-of-river and water supply infrastructure HP projects.*

Project size	No. of project components	Environmental burden savings through ecodesign measures	
		GWP	ARDP
50 kW	27	3.6%	0.2%
100 kW	33	4.9%	1.0%
650 kW	38	4.0%	1.3%
90 kW	21	10.4%	2.6%
140 kW	19	2.1%	0.1%

The ecodesign results represented small reductions in the overall environmental burdens across all HP projects, with the greatest reductions of between 2.1% and 10.4% for the GWP burden (i.e. GHG emissions). ARDP presented smaller environmental savings, with results ranging from 0.1% to 2.6%. The 140 kW project realised the lowest ecodesign savings, as the installation was located in an existing structure, thus no major construction was associated

with this project. The 90 kW project presented the most notable potential savings due to a relatively large concrete powerhouse structure.

The performance of each ecodesign measures differs considerably with respect to carbon- and resource-efficiency. A breakdown of the percentage change in each impact category burden across each of the ecodesign measures is illustrated in Figure 2.

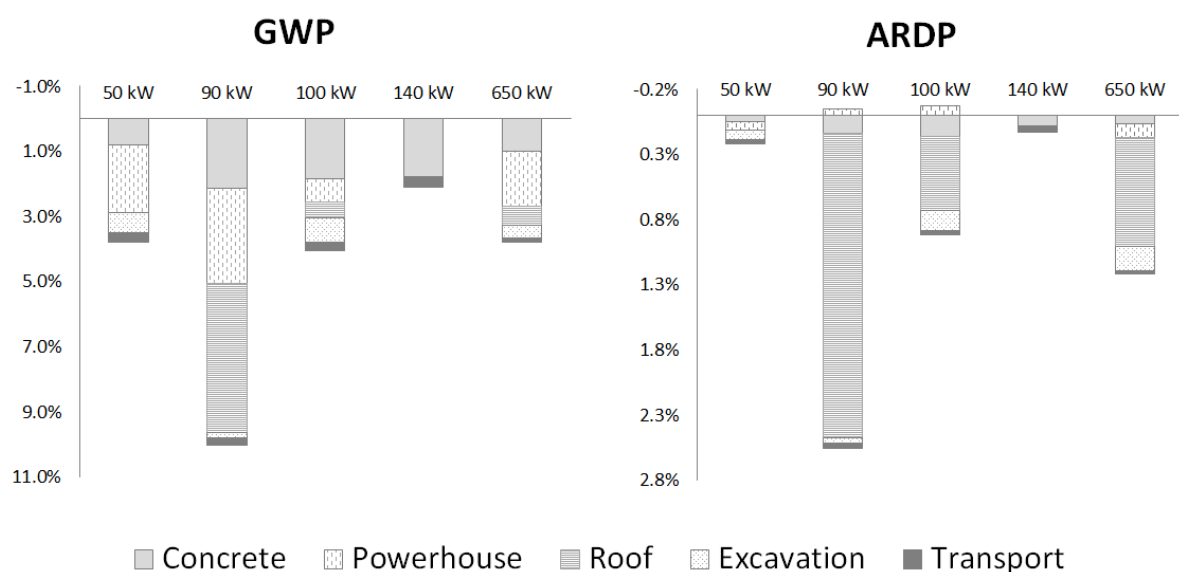


Figure 2. A comparison between the cumulative savings for the GWP and ARDP environmental burdens due to ecodesign measures in the HP projects.

### Powerhouse structure

The 140 kW installation differed from the other HP projects as the powerhouse structure was in place prior to the project being commissioned, thus it was omitted for this part of the study. Changing the powerhouse structure led to a reduction in embodied resource (ARDP) and carbon (GWP) burdens for each of the HP installations. The cumulative changes to the powerhouse presented notable savings for GWP, up to 3.3% savings of the total project burden. However, this did not translate into significant ARDP savings as a maximum reduction to the overall burden of 0.15% was observed. The substitution of concrete with

wood led to avoided burdens, yet the addition of paint and treatment of the wood reduces the potential impact savings in the powerhouse. The treatment of wood ensures the structure has an extended life, to provide a similar lifespan of the turbine and generator of at least 50 years, despite potentially the four HP installations with powerhouse structures. Based on the three HP installations that applied all five ecodesign measures, changing the powerhouse structure accounted for between 32-48% of GWP savings and 3-12% of ARDP savings. Therefore, changing the powerhouse structure has a more substantial impact on carbon savings compared to resource savings.

#### *Concrete selection*

Ecodesign relating to concrete selection demonstrated savings of up to 2.1% and 0.16% for the GWP and ARDP burdens, respectively. The savings were greater for water supply infrastructure HP installations, averaging 1.9% for GWP and 0.11% for ARDP, compared with average GWP and ARDP burdens savings of 1.21% and 0.09% for run-of-river installations. This was due to a larger quantity of concrete used in water supply infrastructure installations per kW capacity. Of the three HP projects which adopted all five ecodesign measures, concrete savings demonstrated an average contribution of 27% and 9% for the GWP and ARDP burdens to the total ecodesign savings for the projects. Similar to powerhouse structure changes, the concrete savings weighted towards carbon savings as opposed to resource savings. The use of precast sections in HP installations was found to present the greatest potential for material savings, but can also lead to financial and time savings during the installation process.

#### *Roof materials*

In three of the case studies, changing the roofing material was considered as an ecodesign measure to promote carbon and resource savings. In one case, the 90 kW installation, applying ecodesign to the roofing materials and replacing the sheeting with slate led to 4.6% and 2.3% reductions for the GWP and ARDP burdens, respectively. This proportionately accounted for 44% GWP savings and 89% ARDP savings for the 90 kW project. On the other hand, only 0.5-0.6% and 0.8-2.3% savings for the GWP and ARDP burdens were noted for the 100 kW and 650 kW projects. The replacement of corrugated iron sheeting with roof slates presented an ecodesign measure where local materials used for roofing reduce both carbon- and resource-burdens. In particular, the promotion of locally-sourced materials such as roof slates is an ecodesign measure can reduce transport demands for a project and it could be applied to other types of renewable energy systems.

#### *Excavation work and transportation*

Project excavation and transportation activities demonstrated different levels of impact and potential ecodesign savings for GWP and ARDP burdens. Ecodesign savings associated with excavation work ranged from 0.05-0.77% and 0.01-0.19% for GWP and ARDP, respectively. Transportation accounted for savings of between 0.12-0.29% for the GWP burden category and 0.02-0.04% for ARDP burden. These savings accounted for the knock-on impacts of changing the building super-structure and the existing and variable conditions presented on each site in relation to excavation work. For ARDP, applying ecodesign measures to excavation work presented more substantial savings than through transportation activities. Reducing fuel consumption in both of these activities presented savings for both carbon and resource burdens, yet more substantial savings are noted for the ARDP burden.

### **3.2 Materiality thresholds and ecodesign**



Adopting materiality thresholds can lead to the omission of minor components that cumulatively contribute significantly to the environmental burdens of HP installations (Gallagher et al., 2015c), thus potentially underestimating overall project burdens. Considering GWP and ARDP as two burden categories, Figure 3 shows the component contributions for each of the case studies before and after ecodesign measures. A breakdown of the percentage environmental burden contributions of each component for GWP and ARDP are included in Table SI.2 and SI.3 in Supplementary Information. This also includes the ranking of these components based on whether they fall in or out of the 0.5% or 1% materiality thresholds, as advised by ISO (2006) and Gallagher et al. (2015b), respectively.

Differences in the number of components captured for GWP and ARDP by using different materiality thresholds are evident in Figure 3. No distinct pattern was observed for the environmental burdens of components falling in and out of the 0.5% or 1.0% thresholds for either the size or type of HP installation. However, it should be noted that some project components e.g. the pipework, turbine and generator, remained as high-ranking contributions to the overall environmental burdens of the projects. The number of project components remained the same for almost all projects, with new components categories evident only for the 90 kW project with the replacement of the powerhouse structure and roofing materials. The contributions of these alternative materials were added to existing items for the other HP projects.

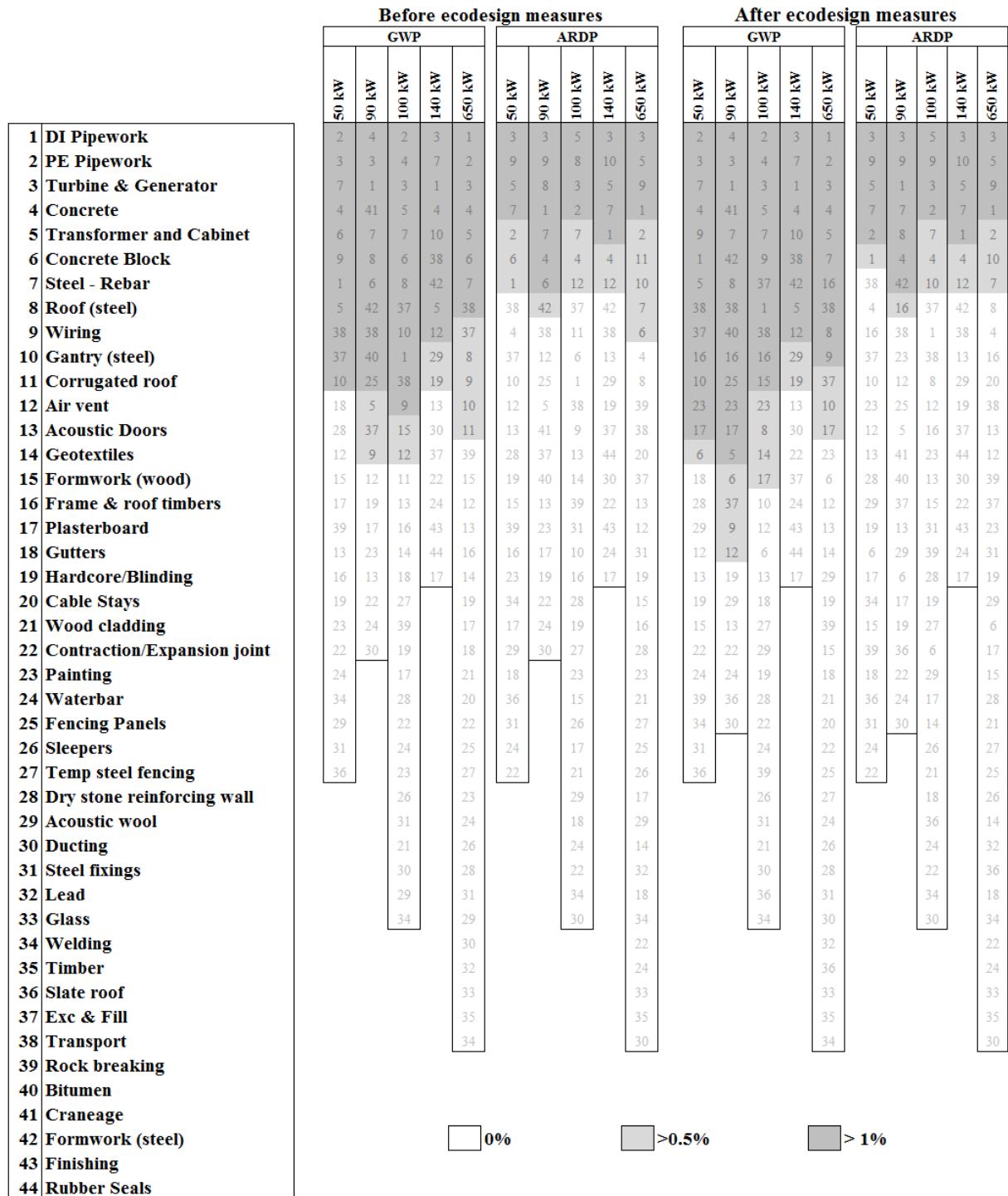


Figure 3. Ranking of project components based on their environmental burden contributions for GWP and ARDP in each of the HP projects.

The use of a materiality threshold can lead to omissions of small contributions for both burden categories. For example, prior to applying ecodesign measures, the concrete blocks (Item No. 6) were captured by the 1% threshold for GWP. However, after ecodesign, this

component would fall outside this threshold and not be captured using current threshold guidelines. In contrast, the majority of wood contributions (Item No. 16) was only captured after ecodesign measures were applied, with a small fraction omitted prior to ecodesign due to the materiality threshold. Overall, the use of a 1% materiality threshold to capture the environmental impacts of a renewable energy system can lead to inaccuracies of results, especially when ecodesign opportunities and multiple burden categories are to be considered.

#### **4 Conclusions**

This paper provides evidence for the potential of ecodesign measures to reduce the environmental burdens of modern hydropower (HP) installations, and indeed other renewable energy systems. A number of ecodesign measures were considered and the results demonstrated both carbon- and resource-savings based on an assessment of global warming potential (GWP) and abiotic resource depletion potential (ARDP) burdens. The ecodesign measures examined included: powerhouse structure, concrete selection, roofing materials, excavation work and transportation. Overall, ecodesign was found to reduce life cycle GWP burdens by between 2.1% and 10.4%, and life cycle ARDP burdens by 0.1% to 2.5%.

Despite overall environmental improvements achieved through ecodesign, small increases in ARDP burdens were observed for two case study examples where the powerhouse structures were changed from concrete block to wood frame. Applying the commonly-cited 1% materiality threshold to guide life cycle inventory compilation can lead to significant HP ecodesign measures being missed. In addition to environmental savings, ecodesign has the potential to help the regional economy by using locally sourced materials and deliver time savings in the installation of HP projects, and by implication renewable energy systems more widely.

Future work should consider the effect of using different materials in terms of recyclability, although this will require better data on the lifetime and end-of-life phases of HP installations.

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